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A study of the reading rate and comprehension of 10 aerospace engineers and analysis of the readability of sample company communications were undertaken. The Nelson-Denny Reading Test comprehension scores for the engineers, when compared with scores of a norm group provided by the Nelson-Denny Test Manual, were nearly the same in mean and standard deviation as those for college seniors. The engineers understood about two-thirds of what they read. No significant difference was found between the reading rates of the two groups. However, the mean of the test group vocabulary scores was significantly higher than the norm group mean. The Flesch Readability Formula revealed that all of the documents analyzed had a lower reading ease score (were more difficult) than the Nelson-Denny Reading Test. It was concluded (1) that important information must be repeated; (2) that all engineers should receive instruction in report writing; and (3) that reading efficiency in engineers could be greatly increased by instituting reading improvement programs. Tables and references are included. (CM)

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READING COMPREHENSION AS A FACTOR IN COMMUNICATION WITH ENGINEERS

I. THE COMMUNICATION PROBLEM

Importance of Communication

Suddenly freeze all activity in a large aerospace company and then note what each engineer or scientist was doing at the instant of freeze. From our observations, their activities would fall about equally into one of the following categories: various non-work related activities; reading reports, memos, etc.; writing reports, memos, etc.; personal or phone conversations; attending formal meetings; equipment design, data analysis, laboratory tests.

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Gates (1) reports that "contrary to the stereotype of a chemist as a quiet man in a lab smock bending over a rack of test tubes, the average chemist spends more time in communicating (23.2 hours per week) than in all the rest of his professional activity combined (15.9 hours per week)." Whatever the actual statistics, we can see that a large part of the technologist's time is spent in some form of communication - either transmitting or receiving.

The concept of "communication" has indeed assumed a fundamental role in educational and organizational theory. Tiffin and McCormack (2) have pointed out that communicating and decision-making are the two primary functions of management. Communication has been broadly defined to include all activities which modify human behavior to achieve a goal. Therefore, in communicating, what is received is more critical than what is transmitted or how it is transmitted. In other words, what the worker understands of the boss's message determines what action he takes as a result of the message.

In the study, which we will describe, an attempt was made to determine how much of the message (in the form of reports, memos, journal articles, etc.) the engineer or scientist understands. Our investigation was confined to formal written communication.

Previous Studies on Effectiveness of Communication

A number of studies have been performed on the problems of communication between management and workers. By applying the Flesch readability formula, Paterson and Jenkins (3) found that the language of most instructions and personnel forms for industrial workers was much too difficult. Communicating in language the "average man" can understand has been stressed in

advertising, but neglected in industrial relations.

A study was made by Dahle (4) on the effectiveness of various methods of transmitting information to employees. The three test groups were college students, factory workers, and employees of a mail order house. Best results were obtained if the information was presented orally at the same time that written material on the subject was made available.

Colby and Tiffin (5) used the Nelson Silent Reading Test (published 1931) to measure the reading ability of 518 supervisors in seven Indiania manufacturing plants. These tests showed that the supervisors' mean grade level of reading ability was slightly above the tenth grade.

Inadequacies of Previous Work

Past investigations appear to be most concerned with communication problems in production-oriented companies. In a search of references on reading and communication studies done within the past twenty years, we could not find any reports of studies with high-level professional groups in organizations oriented toward application of advanced technology, such as aerospace companies.

In addition, the information flow in most of the studies seems to

be linear - going down the organization ladder from management with a little backtalk from the lower depths. The impression received is that a wave of management memos, directives and instructions is breaking over the pyramidal array of boxes in the organization chart. Then out from all the little boxes flows an answering backwash of reports, proposals, specifications and so forth.

In an aerospace company this flow of written material resembles more a whirlpool. Documents go to other people within a department, to persons outside a department on the same level, from line departments to project offices, to agencies outside the company, from outside agencies to project offices and on and on. To add to the confusion, large portions of one document will reappear in another one. An important point in reference to communication in aerospace companies is that the generation of written material is as essential a part of output as the production of missiles.

Objectives of Study

In this investigation we have tried to fill a gap in knowledge of communication effectiveness by using test subjects who are college graduates, employed by a company principally engaged in

research and development rather than production. The specific questions which the study sought to answer were:

1. Do engineers have significant problems in understanding written communication?
2. If a problem exists, is it due to the engineers' lack of ability to comprehend or is the material too difficult to read?
3. Is the rate of reading so slow as to seriously affect efficiency?
4. Should reading improvement and technical writing programs to improve efficiency be considered?

II. METHODS OF INVESTIGATION

Measurment of Reading Comprehension

A standardized reading test was selected for determining reading ability. Strang, McCullough and Traxler (6) have evaluated almost all the available reading tests. We chose the Nelson-Denny Reading Test (7), which has been in use since 1929, because it is: 1) one of the few tests suitable for adults with college education; 2) the only test with grade norms extending up through the senior year of college; and 3) easy to administer and score.

The test is in two parts: a 100-item multiple-choice vocabulary

test and a 36-item comprehension test based on eight reading selections. A one-minute rate test is included in the comprehension portion. Ten minutes are allowed for the vocabulary test and twenty minutes for the comprehension test.

Evaluations of the test are given in the Fourth (8) and Sixth Mental Measurements Yearbook (9). All the reviewers said that the test was well-constructed with a clear format and unambiguous items. The one-minute rate test was found to be too short for satisfactory reliability.

Townsend (9) found that the norm groups were carefully constructed and described, but he criticized the sparse use of scientific terms in the vocabulary test. He stated that the comprehension material was representative of college liberal arts textbooks and questioned the carry-over to business and professional reading.

Orr (9) noted that the comprehension passages derive their difficulty from what is essentially poor writing, i.e., long, involved sentences and construction.

Booker (8) felt that the time limits for the test are rather brief. This places a premium on rapid reading and tends to make

the test one of speed rather than power. Careful reading, re-reading, and deliberation are penalized, thus preventing a great many students from displaying their maximum performance.

Test Group

We administered the Nelson-Denny Reading Test, Form A, to ten engineers at an aerospace company in Massachusetts. Seven of the group volunteered to take the test while three were asked to do so by their supervisor. The test group included only engineers who spend a substantial amount of time in reading as part of their jobs.

We encountered difficulty in obtaining volunteers. Some said that they dislike taking tests; others claimed to be too busy. We suspected that a large portion of those refusing to take the test knew that they were poor readers. If true, this would bias upward the mean score of the test group.

The three non-volunteers were apprehensive about taking the test and wanted to know what would be done with the test results. Their supervisor explained that the results would indicate who was more suitable for tasks which involved developing programs from written descriptions of physical processes. They are

engaged in complex computer programming operations.

Table I summarizes the information obtained from brief interviews with each participant. Since the meaning of job titles varies widely, standardized job titles are used instead of actual ones. Supervisor 3 is the highest rank. He is either in charge of a project office or supervises 50 to 100 people in a line department. In ascending order of rank, the engineers' title are junior, assistant, associate and senior. The average number of hours the test subjects claimed to spend in reading is noted in the Table I; however, we are dubious about some of the figures.

Measurement of Readability

Smith and Dechant (10) have an excellent review on the subject of readability. They explain that readability is not an easily defined concept since it depends on the interaction of many factors. Because communication between writer and reader is never perfect, readability cannot be absolute. Table II is a list of factors which Smith and Dechant identify as affecting readability.

Various formulas have been developed to indicate readability by a quantitative measurement of some of the factors noted in Table II. In developing a formula, the goal is to get the best prediction

TABLE I

TEST GROUP DATA

Test Subject	Job Title	Degree(s)	Age	Years Since Bach. Degree	Reading At Work Hrs/Wk	Reading Outside Hrs/Wk
1	Sup. 3	B.M.E.	36	15	25	20
2	Sr. Eng.	B.E.E.	43	22	20	15
3	Sup. 1	B.E.E.	40	13	10	5
4	Sr. Eng.	B.E.E.	38	14	5	2
5	Ass't. Eng.	B.A., M.S.	26	5	20	25
6	Sup. 2	B.S.	37	16	15	25
7	Assoc. Eng.	B.A.	40	6	25	5
8	Jr. Eng.	B.S.	25	1	10	10
9	Ass't. Eng.	B.S.	34	6	10	10
10	Assoc. Eng.	B.S., M.A.	39	17	18	25

TABLE II

FACTORS IN READABILITY

1. Word length
2. Percentage of different words
3. Sentence length
4. Personal references
5. Number of syllables
6. Number of pronouns
7. Number of affixes
8. Number of prepositional phrases
9. Number of difficult words according to word lists
10. The use of simple or complex sentences
11. Density and unusualness of the facts
12. Number of pictorial illustrations
13. Interest and purpose
14. Concept load - abstractness of words
15. Organization of the material and format
16. Interrelationship of the ideas

with the smallest number of factors, and also to use factors that are easy to measure.

The most widely used measure for adult reading is the Flesch Readability Formula (11). Flesch measures only two elements of readability - sentence length and number of syllables. These factors are combined to give a "reading ease" score ranging from 0 to 100.

R.E. ("reading ease") = 206.835 - .846 (wl) - 1.015 (sl)

where:

wl = number of syllables per 100 words

sl = average sentence length

"Reading Ease" scores will tend to follow the pattern shown in Table III (taken from reference 11).

We applied the Flesch Readability Formula to typical material that the test group engineers read in their work.

III. RESULTS OF STUDY

Reading Test

Test scores on the Nelson-Denny Reading Test are tabulated in Table IV, along with the means and standard deviations for the entire test group. The test subjects are arranged in decending order of comprehension scores. A blank space in the column of

TABLE III

PATTERN OF "READING EASE" SCORES

"Reading Ease" Scores	Description of Style	Typical Magazine	Syllables per 100 words	Average Sentence Length in Words
0 to 30	Very difficult	Scientific	192 or more	29 or more
30 to 50	Difficult	Academic	167	25
50 to 60	Fairly Difficult	Quality	155	21
60 to 70	Standard	Digests	147	17
70 to 80	Fairly Easy	Slick-fiction	139	14
80 to 90	Easy	Pulp-fiction	131	11
90 to 100	Very Easy	Comics	123 or less	8 or less

TABLE IV

TEST SCORES FOR-
NELSON-DENNY READING TEST

Test Subject	Compre-hension	Vocab-ulary	Rate	% of Test Completed	
				Comp.	Vocab.
1	64	88	359	100	100
2	64	81	436	100	85
3	58	77	238	100	86
4	54	—	327	89	—
5	50	60	513	100	97
6	46	89	318	100	100
7	42	43	226	72	49
8	38	48	275	100	75
9	38	—	207	64	—
10	34	—	275	64	—
Max. Possible Score	72	100	—		
Mean	48.8	69.4	317		
Dev.	11.3	18.9	97		
Coefficient of correlation with comprehension score		0.72	0.52		

vocabulary scores indicates that the sub-test was not taken by the subject. Coefficients of correlation were calculated between vocabulary and comprehension scores and between rate and comprehension scores. Strong linear relationships between reading comprehension and vocabulary knowledge and also between comprehension and reading rate are evidenced by the values for correlation given in Table IV. Statistical tests were made which proved the correlation coefficients to be significant at the .05 level.

Due to the small size of the test group, statistically significant correlations could not be made between test scores and interview data, such as age and hours spent in reading.

In order to evaluate the test scores, it is necessary to compare them with the scores of a norm group as provided by the Nelson-Denny Test Manual (7). The mean and standard deviation of the comprehension scores for college seniors (grade 16) are nearly the same as those of the test group. Statistical test using the Student-t and chi-square distributions show no significant differences at the .05 level between either the means or the standard deviations of the two groups. Thus, the percentile ranking of scores for grade 16 are used to evaluate the results. The percentile rankings of the test subjects for comprehension,

vocabulary and rate are given in Table V.

Statistical tests were made to assess the significance at the .05 level of any differences between the test group and norm group scores for rate and vocabulary. No significant difference was found between the rates. However, the mean of the test group vocabulary scores (69.4) was significantly higher than the mean for the norm group (50.50).

Application of Flesch Readability Formula

A large quantity of written material is both generated and received at any aerospace company. Obviously, our sampling, shown in Table VI, is limited; however, we believe that it is typical of the material encountered by engineers.

All the documents checked with the readability formula have a considerably lower "reading ease" score than the Nelson-Denny Reading Test. Document 2, which has the highest score, is a well-written report that is much above the average in clarity. The "reading ease" score of 41 for this document would appear to be representative of the upper quartile of documents.

Readability problems are highlighted by Document 5, the employment advertisement, which seeks an engineer who will assume "total re-

TABLE V

PERCENTILE RANKING OF TEST GROUP
WITH COLLEGE SENIORS AS NORM GROUP

Test Subject	PERCENTILE RANK		
	Comprehension	Vocabulary	Rate
1	92	99	78
2	92	97	94
3	76	95	27
4	64	—	66
5	54	76	98
6	41	99	62
7	31	34	21
8	17	48	44
9	17	—	13
10	10	—	44

TABLE VI

APPLICATION OF FLESCH READABILITY FORMULA

Type of Material	Syllables per 100 Words	Average Sentence Length in Words	"Reading Ease" Score*	Classification
1. Supervision Newsletter	195	29	12	Very Difficult
2. Synopsis of space vehicle study program	169	22	41	Difficult
3. Technical analysis of radar problem	187	34	14	Very Difficult
4. Air Force document giving direction to contractors	196	26	15	Very Difficult
5. Employment Advertisement	221	29	-9	Incomprehensible?
Selections in Nelson-Denny Reading Test	149	20	51	Fairly Difficult

*The higher the score, the easier the material.

sponsibility for effective communications". With a score of -9, this communication "broke the bell" on the Flesch readability scale.

IV. SIGNIFICANCE OF RESULTS

Portion of Written Material Understood

The mean score of the test group in comprehension was 48.8 out of a maximum possible score of 72. Thus, the average engineer in the group understood about 2/3 of what he read. By applying the Flesch Readability Formula to typical material that the engineer must read, we showed that this material is much more difficult than the Nelson-Denny reading selections. Therefore, it is possible that the average engineer misunderstands at least 1/3 of what the writer of a report or memo is trying to communicate.

However, in making the above estimates of distortion in written communication, we assumed that the reader does not reread the material. Obviously, if the engineer is sufficiently motivated he will improve his comprehension by a careful study of the document. The limiting factor is then the quality of the writing, which appears to be generally poor.

Correlations Between Test Scores

The high correlation (.72) between vocabulary and comprehension scores is to be expected. Smith and Dechant (10) discuss studies which show that vocabulary is highly related to comprehension.

Studies on the relationship between reading rate and comprehension tend to be contradictory. Correlations between the two scores ranging from slight negative to high positive have been reported (10). This variability of results may simply be due to the limited time allowed for the comprehension test. Consequently, Preston and Botel (12) found that the correlation between rate and timed comprehension was a statistically significant coefficient of .48, while the correlation between rate and untimed comprehension was .20, and not significant. The correlation coefficient of .52, which we obtained, agrees fairly well with the value of .48 for the timed comprehension test.

Research performed by Carlson (13) also helps to explain the relationship between speed and comprehension. He found that individuals with high intelligence tend to comprehend better when reading rapidly than when reading slowly; those with average or low intelligence comprehend better when reading slowly than when reading rapidly.

Differences Between Test Scores

Test group vocabulary scores were significantly higher than those of college seniors while the comprehension scores were the same. In fact, every test subject who took the vocabulary test showed a higher percentile score on vocabulary. This seems to indicate that comprehension does not improve after we leave college, although we keep learning new words.

In the manual for the Nelson-Denny test, the authors state that a student with a higher percentile rank in vocabulary than in comprehension may have the word power to comprehend to the level of the vocabulary percentile, but he is not using that word power with expected skill. "The difficulty may be a matter of interest, of motivation, of concentration, of background deficiency, or of such things as regressing, vocalizing, and word-by-word reading".

Approaches to Improving Comprehension

The results of our study indicate the following possible approaches to reducing "noise and distortion" in written communication:

1. Important information must be repeated both in the same communication and by sending additional messages. A combined written and oral presentation is most effective.

2. All engineers should receive instruction in report writing to improve the quality of written communication.

3. Reading improvement programs could greatly increase the reading efficiency of engineers. Studies (6) have shown that adult participants in reading programs have retained acquired gains in rate and comprehension.

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